ECONOMIC OPERATION OF POWER SYSTEMS

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Lecture: **3** Tutorial: **3** Practical: **--** Total: **6**

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Economic load dispatch

The unit commitment study

It optimally defines the required generators to meet the expected load and to provide a specified margin of operating reserve over a specified period of time

The economic dispatch

It determines the output power of each plant that would minimize the overall fuel cost. This represents a coordination process between the unit productions in an economic manner.

System Constraints

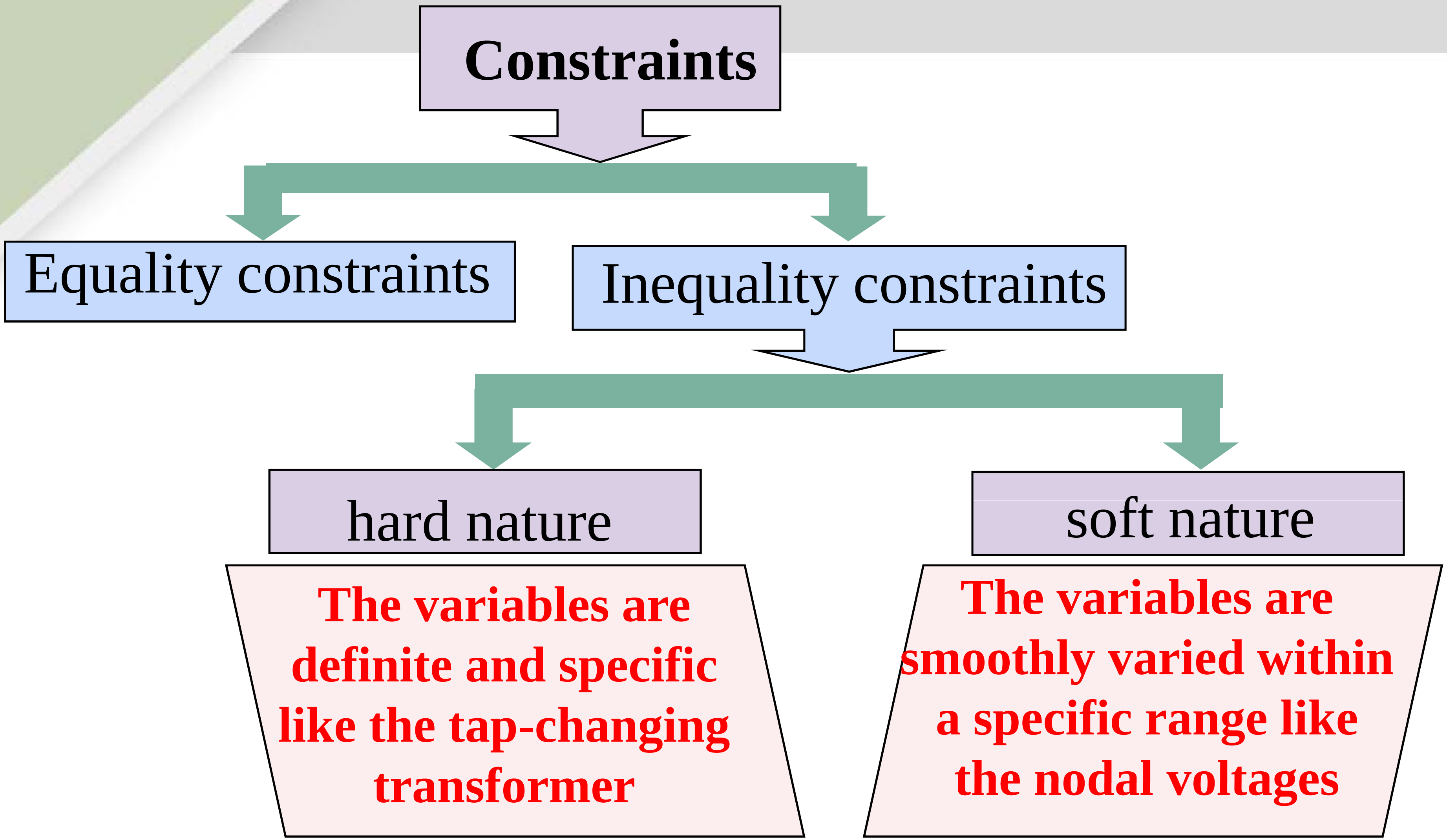
The technical limitations that have not to be violated under any condition

The violation of these constraints affects the power quality and the general operation of the power system and causes stability problems

The constraints can be divided into two groups: equality constraints and inequality constraints

Inequality constraints can have a *hard* nature, where the variables are definite and specific like the tap-changing transformer, or a *soft* nature, where the variables are smoothly varied within a specific range like the nodal voltages

System Constraints



System Constraints

Equality Constraints

The main equality constraints are the basic load flow equations that establish the flow balance equations

For example, the equality constrains according to Newton-Raphson Method are

$$P_i = \sum_{j=1}^{n} V_i \cdot V_j \cdot y_{ij} \cdot \cos(\delta_i - \delta_j - \gamma_{ij})$$

$$Q_i = \sum_{j=1}^{n} V_i \cdot V_j \cdot y_{ij} \cdot \sin(\delta_i - \delta_j - \gamma_{ij})$$

System Constraints

Inequality Constraints

Generator constraints

The thermal stability of generators requires that the total VA "$\mathbf{S_g}$" loading of any generator has not to exceed a certain maximum value $\mathbf{S_{g\text{-}max}}$:

$$\boxed{S_g = \sqrt{P_g^2 + Q_g^2} \le S_{g,\max}}$$

where: P_g and Q_g are the active and reactive generated power respectively

System Constraints

Inequality Constraints

Generator constraints

The upper limit of the active power P_{max} is constrained by the thermal consideration

The lower limit P_{min} is constrained by the flame instability of the boiler

Consequently, the generated power from any unit "P_g" has to be kept within the limits:

$$\boxed{P_{min} \leq P_g \leq P_{max}}$$

System Constraints

Inequality Constraints

Generator constraints

There are upper and lower limits for the reactive power of the generator

These limitations are defined by the overheating of the rotor for the upper limit and the stability limit of the machine for the lower limit

$$\boxed{Q_{min} \leq Q_g \leq Q_{max}}$$

System Constraints

Inequality Constraints

Voltage constraints

Both the magnitudes and angles of node voltages have to be controlled in order to keep them within acceptable limits

The power quality necessitates that the voltage magnitudes at load terminals are kept within specific limits or else the equipments will not operate satisfactorily

The regulation of the voltage starts from the generators (exciters) to reduce the cost of extra voltage regulating devices

System Constraints

Inequality Constraints

Voltage constraints

The upper limit of phase angles is defined regarding the transient stability of power systems

On the other hand, the lower limit of the angles is defined taking into account achieving an efficient utilization of transmission facility

Typical operating angle of transmission line lies between 30° - 45°

System Constraints

Inequality Constraints

Voltage constraints

$$\left|V_{min}\right| \leq \left|V_n\right| \leq \left|V_{max}\right|$$

$$\delta_{min} \leq \delta_n \leq \delta_{max}$$

where: is the magnitude of node angle with an angle of **d_n** at node **n**

System Constraints

Inequality Constraints

Running spare capacity constraints

To ensure the existence of enough spinning reserve to overcome any emergency situation

The generation should guarantee a minimum spare capacity in addition to load demand and power losses

$$\boxed{P_g > P_{Load} + P_{loss}}$$

This difference, i.e. spare capacity, is defined according to economic issues and technical aspects like the ramping rates of the generators

System Constraints

Inequality Constraints

Transmission line constraints

There is a thermal capability of each transmission line that defines the allowed flow of active and reactive power

The transmitted power is limited as follows

$$\boxed{P_{T.L} \leq P_{T.L,max}}$$

Where $P_{T.L,max}$ is the maximum loading capacity of the transmission line

System Constraints

Inequality Constraints

Network security constraints

Violation of constrains can take place subsequent to abnormal conditions like a line outage, either scheduled or forced, which affects the security of the network

Sometimes a so called (*x-1 study)* is performed to examine the reliability and security of the system

The *x-1 study* means that the network is studied with outage of one branch at a time

System Constraints

Inequality Constraints

Transformer tap settings

Sometimes, there is a possibility to change the voltage in steps, i.e. to chose between different values rather than varying the voltage smoothly

$$\boxed{0 \leq t \leq t_{max}}$$

For auto-transformers, t_{max} can be unity

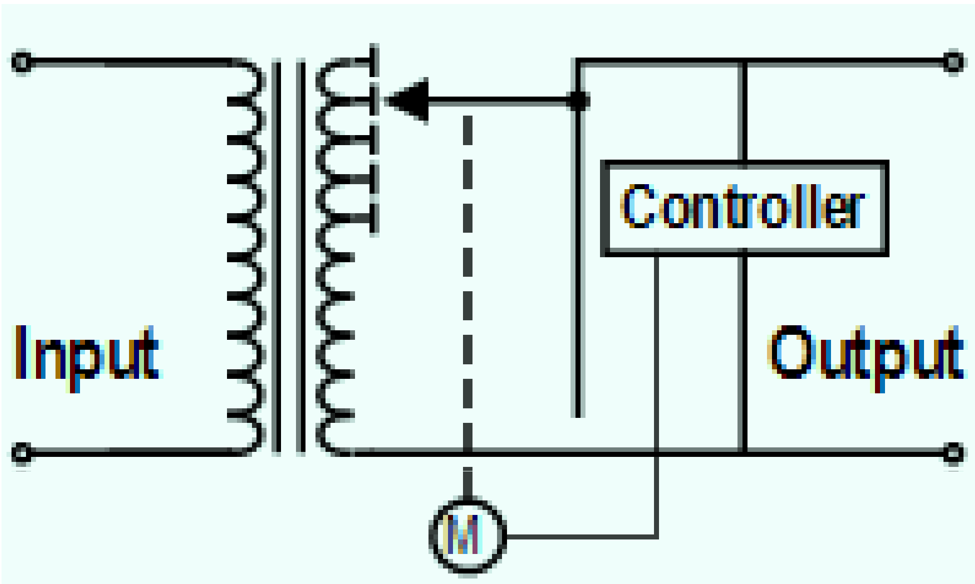
System Constraints

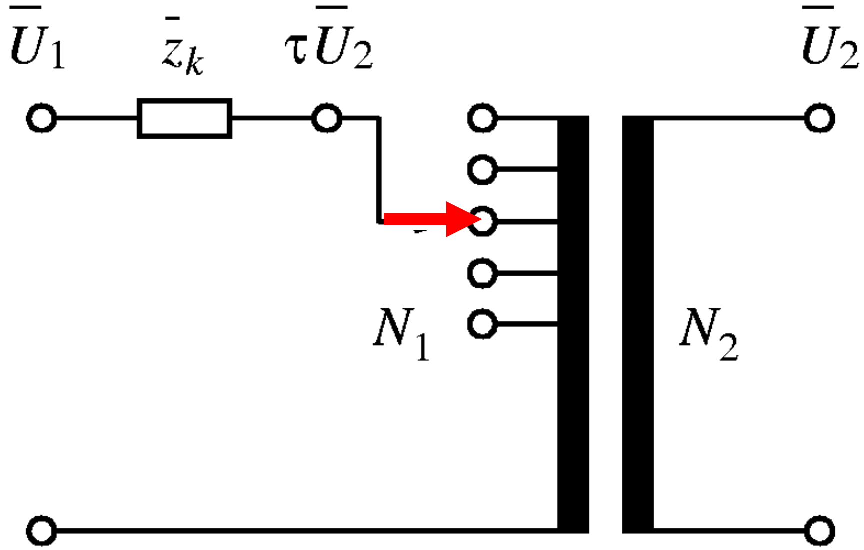
Inequality Constraints

Transformer tap settings

Phase shift-ing transformers have phase shift limits

$$\boxed{\theta_{min} \le \theta \le \theta_{max}}$$





Economic Dispatch Problem

Economic load dispatch concerns with the operating cost rather than the fixed cost

Only fuel cost is considered in the study where all other costs that are depend on the generated power will be included in the expression of the fuel cost

Obviously, the cost of fuel is concerned since thermal plants are assumed

An early approach of power dispatch was to supply power from the most efficient plant till the point of maximum efficiency and then from the next most efficient plant and so on

Economic Dispatch Problem

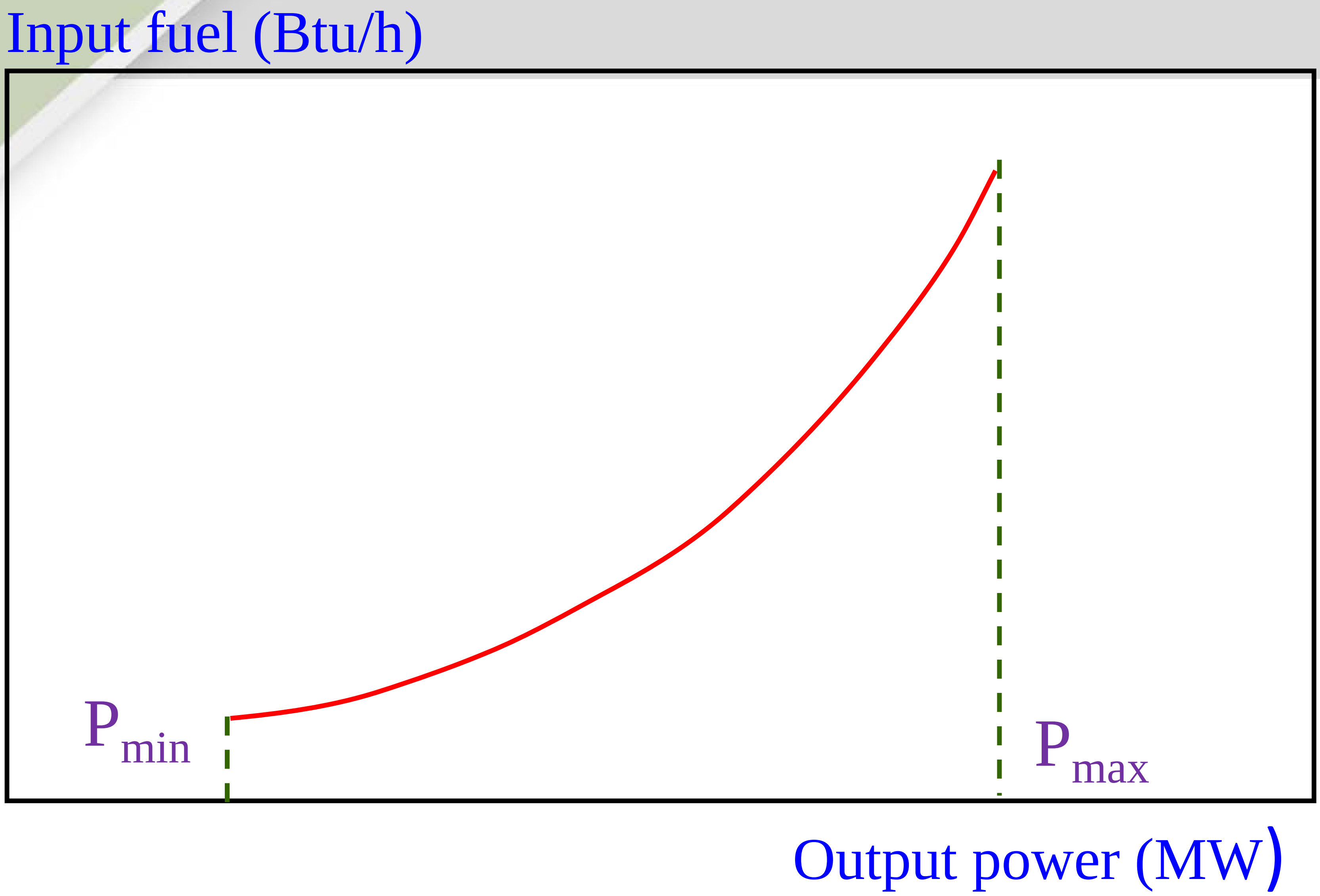
The locations of power plants and the transmission losses have to be considered

Generating power in far plants requires supplying the transmission losses in addition to the load demand

Economic distribution of load demand among generating units necessitates expressing the cost as a function of the generated power

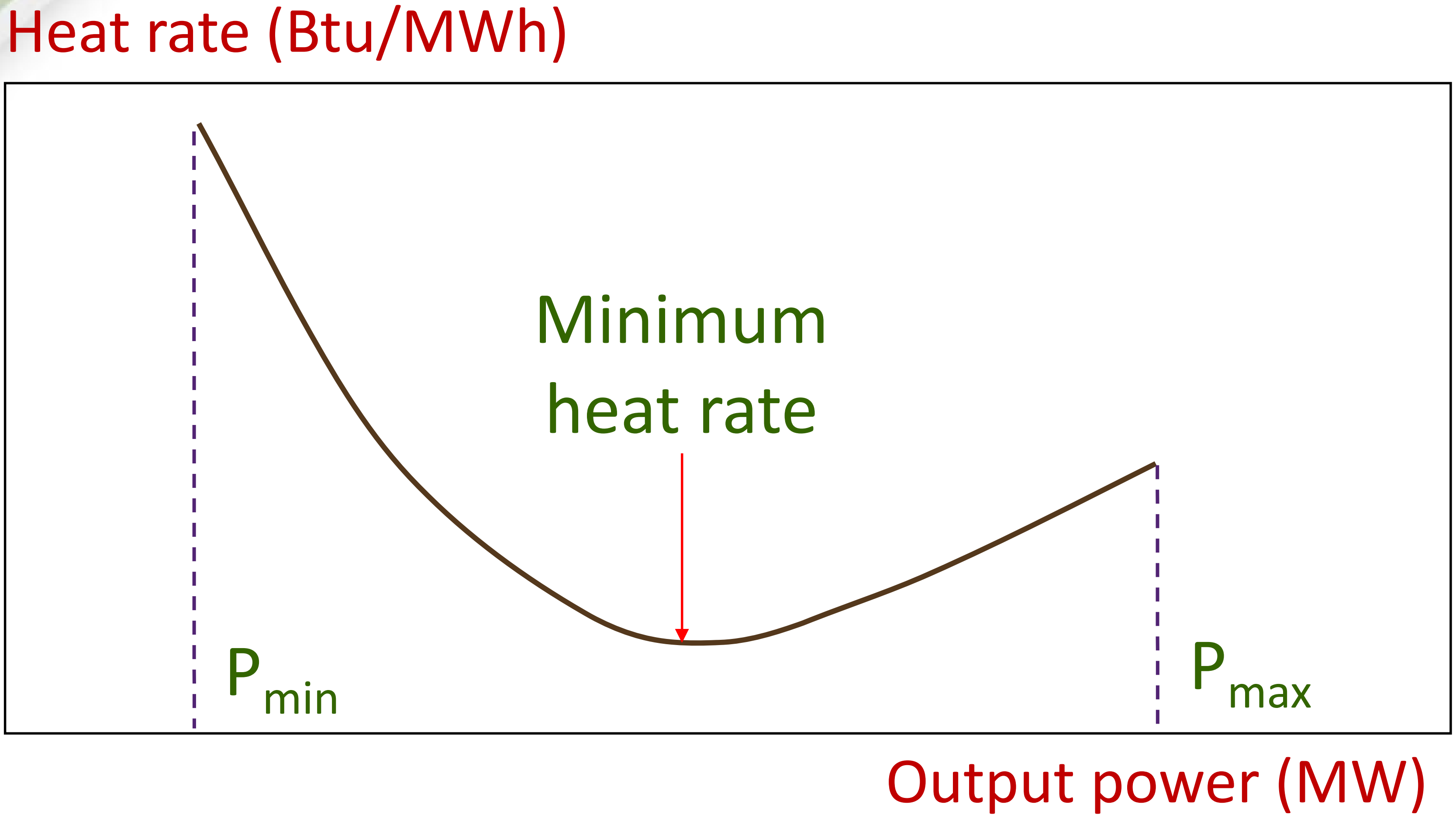
The performance curve of **boiler-turbine-generator** set is required, which is called input-output curve

input-output curve



Economic Dispatch Problem

The incremental heat rate "the heat rate" is the ratio of input fuel to the corresponding output power (Btu/MWh)



Economic Dispatch Problem

The incremental fuel rate is given as

$$\text{Incremental fuel rate} = \boxed{\frac{\Delta\,(\text{input})}{\Delta\,(\text{output})} \approx \frac{d\,(F)}{d\,(P)}} \quad (\text{Btu/MWh})$$

With **F** is the input fuel and **P** is the output power

The reciprocal of the incremental heat rate is known as ***the incremental efficiency***

To operate at the maximum fuel efficiency, the point of the minimum heat rate has to be defined

Multiplying the incremental fuel rate by the fuel cost, the incremental fuel cost is obtained in ($/MWh)

Example

The input fuel in (Btu/h) for a power plant with minimum and maximum power of 10 and 100 MW respectively is given by:

$$F=(40+4*P + 0.012*P^2)*10^6$$

where P is the generated power in (MW). Plot the input-output curve of the plant. Calculate the heat rate and plot its curve against the output power. Assuming a fuel cost of $0.12*10^{-6}$ \$/Btu, calculate the incremental fuel cost in \$/MWh and plot its curve against the output power.

The fuel is given as:

$$F=(40+4*P + 0.012*P^2)*10^6$$

Also, the heat rate can be calculated from equation

$$\boxed{\text{Heat rate} = \frac{\text{input fuel (Btu/h)}}{\text{output power (MW)}}}$$

The fuel cost as a function of the output power is:

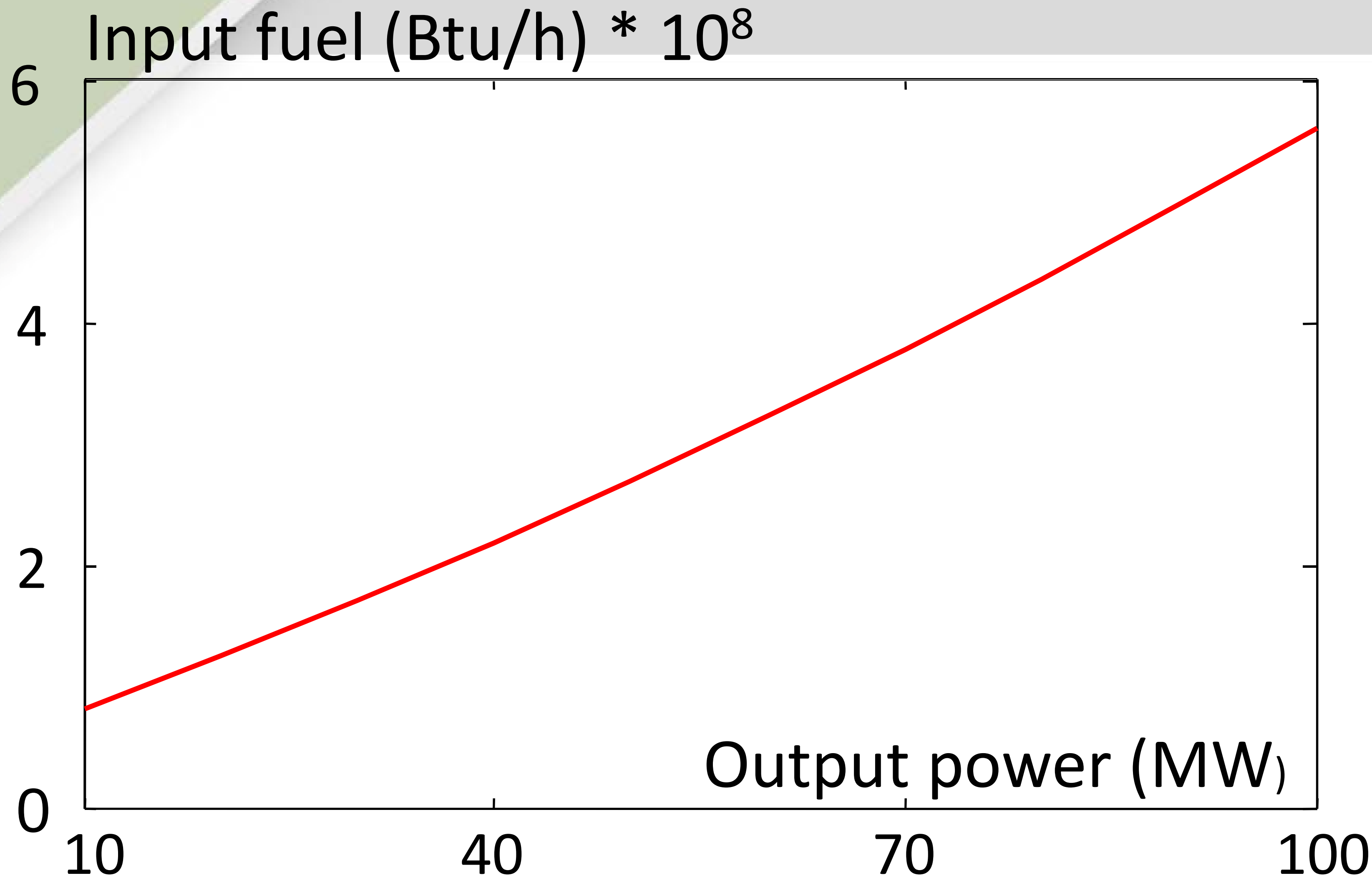
$$C=0.12*10^{-6} *F= 4.8 + 0.48*P + 0.0014*P^2 \text{ (\$/h)}$$

The incremental fuel cost is:

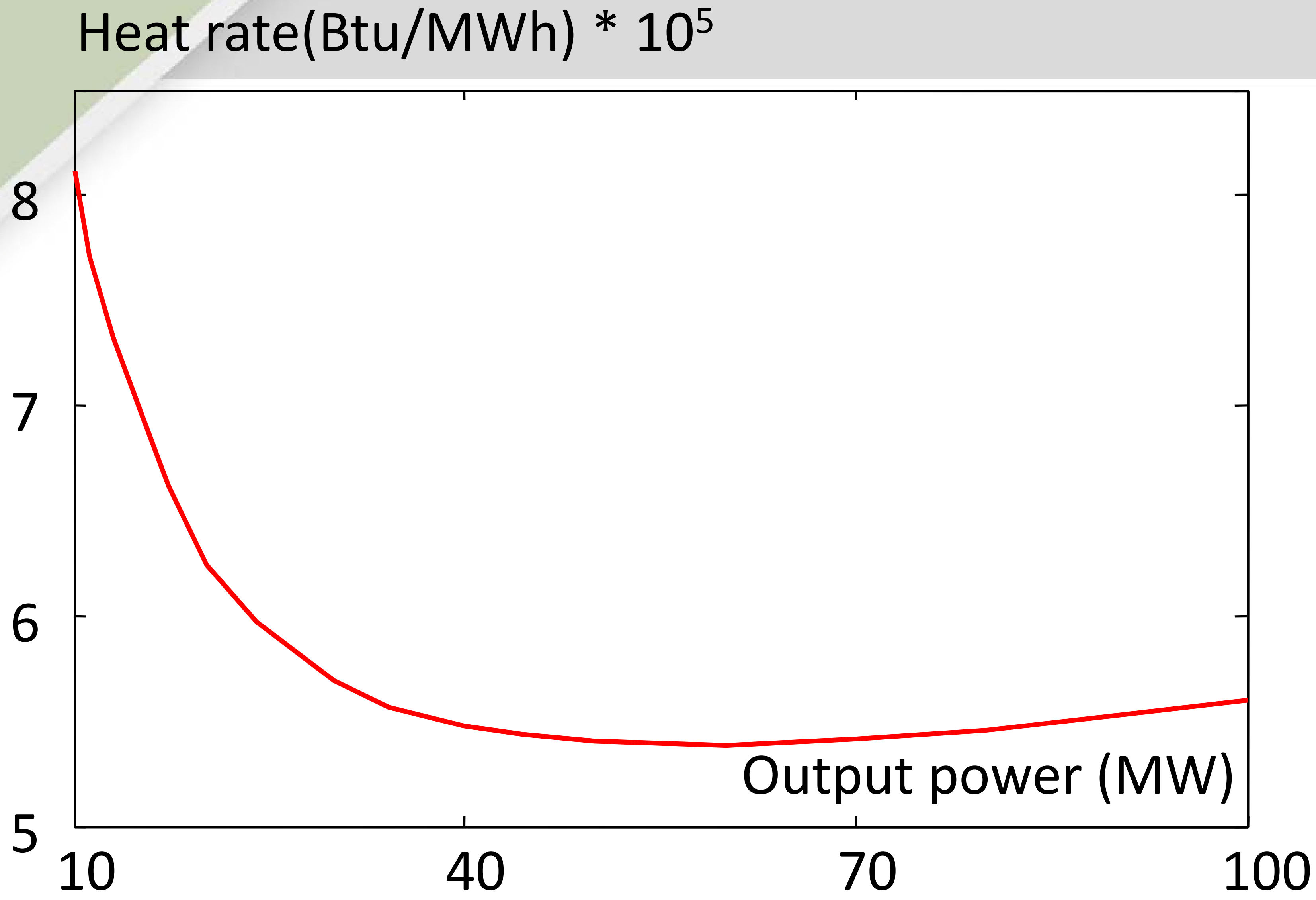
$$I_{fr} = 0.48 + 0.0028*P \text{ (\$/MWh)}$$

P (MW)	10	20	30	70	80	90	100
$F*10^{-6}$ (Btu/h)	81.2	124.8	170.8	378.8	436.8	497.2	560
Heat rate $*10^{-6}$ (Btu/MWh)	8.12	6.24	5.69	5.41	5.46	5.52	5.6
IFR ($/MWh)	0.5	0.53	0.56	0.67	0.7	0.73	0.76

Input output curve



Heat rate curve



Incremental fuel cost